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ABSTRACT

Economic models cannot give us the information society needs to define the set of possible future scenarios facing the world. Thus "optimal" economic plans are susceptible to being overwhelmed by feedbacks of which humans are ignorant as economic systems increasingly stress ecosystems. These concerns have lead to a call for the maintenance of a fixed natural capital stock as a safe minimum standard. This paper analyzes the reasoning behind defining a class of inputs to production as natural capital. Two motivations are shown to be important justifications for the new class of capital: ecological criticality and non-human intrinsic values. We argue that these justifications require the maintenance of resources which are excluded from exploitation, but that the free market system cannot achieve this goal due to a basic assumption of trade-offs being derived from utilitarianism and the basis of constraints in economic value. Three methods which have been suggested for the protection of natural capital are reviewed; namely: compensating projects, cost-benefit analysis, and scientifically designated limits. Each of these approaches is shown to be inadequate at addressing the concerns which have led to the concept of natural capital. A, fourth, more interdisciplinary and inclusive approach is necessary and a type of systems analysis, employing Sustainability Assessment Maps, is put forward as a method which could fill that gap.

Keywords: natural capital, sustainability, utilitarian, intrinsic values, ignorance.

I. INTRODUCTION

The concern for sustainability has lead to the suggestion that natural capital maintenance is a necessary but insufficient condition. Natural capital tends to be discussed in an all inclusive sense without explicitly recognising the attributes which make it so important. In the following pages the reasoning behind concerns for natural capital maintenance are evaluated and the methods which claim to achieve that goal are discussed. The spectrum of concerns ranges from the anthropocentric utilitarian perspective of neo-classical economics, where natural capital is required to provide income flows, to the role of preventing the loss of critical functions and maintaining stability in ecosystems. This paper moves through the range of perspectives on natural capital to offer a view of what is being discussed by different schools of thought.

The importance of defining a set of inputs to production as natural capital is limited to the extent of being semantics at the extreme of a purely neo-classical viewpoint. Those who regard ecosystems as fundamentally robust, and environmental problems as minor perturbations, view the warnings of neo-Malthusian, environmental pessimists (which drive sustainability concerns) as pure fantasy because they lack adequate scientific evidence. However, the application of risk, uncertainty and ignorance to the decision-making process results in the realisation that the standard approach to the economic modelling of uncertain future events suffers from a narrow reductionist view of knowledge. Rather than continuing the search for an optimal path forward, to which society can be irreversibly committed, the recognition of our ignorance emphasises the need to preserve flexibility by opening out the selection of options. The tendency has been to restrict the decision process to a few ways forward as suggested by a simple linear extrapolation of the past.

An economic view of sustainability in terms of value is confronting an ecological view of sustainability in terms of physical characteristics. The restricted economic outlook has been shown to fail at assuring stability, which is regarded as ecological sustainability, while being able to maintain constant consumption, taken as economic sustainability (Common and Perrings, 1992). Thus, the sovereignty of the consumer can be seen as a potential threat, to the general system, which must therefore be restricted by allowing the requirements of the system to override those of the consumer. The combination of ecological and economic approaches raises issues of a more fundamental philosophical nature. These philosophical issues seem to motivate much environmental concern (Craig et al. 1993, Spash 1994), and are shown below to be directly relevant to the position taken by some prominent environmental economists (as argued by Holland 1994).

Both the ecological and economic approaches require that the factors to be protected are identified, and natural capital be shown as a cause of that protection, as if the issue were one of scientific determinism. However, the definitions of natural capital are then a function of the basic philosophical assumptions of value formation. In particular, adopting a non-anthropocentric perspective recognises that elements of natural capital are of value in themselves and cannot be captured by economic valuation. This has direct relevance to the strategies put forward for natural capital maintenance and their ability to address the concerns which seem to lie behind the need to have a concept of natural capital at all. Once these arguments have been developed, four approaches to natural capital maintenance are discussed: economic valuation, physical compensation, scientific thresholds, and a systems approach.

II. WHY NATURAL CAPITAL?

Redclift (1993 p.19) has argued that the mode of thinking summarised in modern economics is largely responsible for the unsustainable development of both North and South. In his view the pursuit of growth, and neglect of its ecological consequences, has its roots in the classical paradigm which informed both market and socialist economies. Others point to a number of human-induced environmental problems to show that society needs to plan explicitly for sustainability (see Meadows et al., 1992). In contrast, the neo-classical economic viewpoint claims that, even without technological progress, non-renewable resource depletion still allows sustainable development because economic output can be maintained or even increased via substitution (Victor 1991 p.196). Yet, within this framework, rapid resource depletion increases the dependence of the current system upon technological progress to prevent collapse when substitutes are limited. In addition, economic models have erroneously reflected the assumed non-scarcity of environmental source and sink functions (Daly 1991). This assumption is directly acknowledged as inadequate where the common value of such functions are excluded from the selfish calculations of economic persons.

The standard economic model of production includes land, labour and capital. Following Marshall, land is taken to include all "free gifts" of nature and is assumed to be fixed. That is, land is the input to production which humans cannot increase (unlike man-made capital) but only utilise more efficiently. If the concept of natural capital is defined within the neo-classical, utilitarian framework the justifications for its consideration as separate from other capital lie in the degree of substitution between types of capital. Natural capital would therefore seem to be neo-classical land renamed. This could be worthwhile because land was more relevant as an input to an agriculturally based economy while the new name implies use of a wide range of natural resources. However, if natural capital is merely semantics little in the way of new insights to sustainability can be expected. In fact, the application of such a restricted definition raises several problems which show this is far from being the extent of concern. However, before expanding on this point, the argument in favour of natural capital can initially be restricted to the neo-classical framework.

Definitions of natural capital in the literature tend to be vague at best. Typically reference is made to a stock of resource and environmental assets (Berkes and Folke 1992 p.2, Tietenberg 1992 p.582; Jacobs 1991 p.224; Clark 1991 p.329, Pearce et al. 1989 p.3). Natural capital is taken to include those features of nature (such as minerals, biological stocks, and pollution absorption capacity) that are directly or indirectly utilised, or are potentially utilisable, in human social and economic systems. This recognition of indirect values comes from the ecological concern for those features (such as soil and atmospheric structure, plant and animal biomass) that form the basis of ecosystems (Costanza et al., 1991 p.8). The concept of natural capital raises a concern for the indirectly utilised features of nature in a similar way to Boulding's emphasis on the value of stocks, as opposed to flows, in the creation and maintenance of human systems and their improvement over time (Boulding 1966).

While conceptualising the stock of natural capital is an issue for all concerned with its maintenance, this is particularly problematic for the economic approach. In fact, the need to define the economic boundaries of this stock has been obscured by focusing on the maintenance of income flows from capital rather than being concerned for the measurement and meaning of the total stock. For example, Serafy (1991 p.175) has argued that efforts should be concentrated upon measuring income flows and leaving aside the valuation of the total environment. However, income flows cannot be separated from the capital stock from which they are derived. Under this definition, the value of natural capital lies in the amortized value of future benefits that can be derived from the use of the asset (Clark 1991 p.329). The aim of natural capital maintenance is then to maintain the capital yield. This is to be achieved by avoiding diminution of natural resource stocks and deterioration and degradation of the environment. An important differentiation is then necessary in terms of income flows from capital stock reductions, running down natural wealth, as opposed to income from capital yield (only the latter being consistent with sustainability). The former is undesirable because the generation of income by the erosion of capital stock tends to reduce future productivity.

In terms of sustainability criterion, the concern is to achieve a non-declining income flow from capital which maintains or increases utility (Pezzey, 1989). If natural capital is reduced man-made capital will need to compensate for the yield lost. Thus, the Hartwick rule suggests achieving intertemporal efficiency in resource allocation by investing depletable-resource rents in man-made capital, and so maintaining a constant consumption stream (Hartwick 1977). The constant consumption stream is justified by an appeal to a "Rawlsian" approach to intergenerational justice adopted by Solow (1974). The simple Hartwick rule depends upon man-made capital: (i) failing to depreciate, (ii) being a substitute for, rather than a complement to, natural capital, and (iii) being unrelated to rather than produced from natural capital (Victor 1991). Ignoring these problems, maintaining the value of the stock of capital is a necessary condition for Solow-sustainability and therefore measures of that value are required (Common and Perrings 1992 p.30).

As Serafy (1991 p.172) recognises, the use of income flows as a guide to sustainability without regard to the capital stock can be totally misleading. Thus, on this definition, society must know when the natural stock of capital is being run down. The inseparability of the income flow from the stock is similar to the circularity which surrounds the definition of an index for man-made capital. The debate, between neo-classical and Post-Keynesian economists, concerning this problem is known as the Cambridge Controversy. The difficulty is how to define a measure of aggregate capital when the valuation of capital presupposes a particular interest rate but the interest rate is dependent upon the marginal product of capital which varies with the quantity of capital; a circular argument arises (Blaug, 1980 pp.202-208). In fact, once the term capital is taken to apply to the environment all the issues related to man-made capital seem to be relevant to natural capital (as discussed by Victor, 1991). This runs the danger of implying that the environment is actually a subset of man-made capital. If anything the reverse must be true because natural resource inputs are necessary for the production of man-made capital. Thus we need to identify those aspects of natural capital which lie behind its adoption by the environmentally concerned community, and which also do differentiate it from both man-made capital and the neo-classical conception of land.

The concern for stability is perhaps the defining physical characteristic which makes natural capital different from man-made capital. The difference turns on the degree to which natural capital is critical to the human species. Something that is critical for one species may of course be non-critical for another. An event that eliminated the human species but left anaerobic life forms otherwise unaffected could be judged as a non-critical loss of natural capital from the point of view of anaerobic life forms. As rational, economic, human beings our primary concern for criticality refers to the potential implication for ourselves of the loss of some particular form of natural capital. Adopting this anthropocentric viewpoint at a societal level, the loss of natural capital is only crucial in so far as either damage occurs to the economic system or to the survival of the human species.

Typically critical limits can be reached via human actions in the following ways:

(i) Persistently harvesting a renewable resource at a rate that exceeds the maximum sustainable yield; so reducing the stock of the resource until it becomes extinct. In this way a renewable resource might be regarded as moving from the non-critical into the critical category. However, this would only be true to the extent that the species were either economically important or an essential part of ecosystem stability. As standard texts in resource economics show, extinction of species can be perfectly rational and even optimal (Hartwick and Olewiler, 1986 pp.284-287).

(ii) Eroding the assimilative capacity of the environment to the stage where serious threats to economic and human systems occur. In this context a reforestation programme with the aim of carbon fixing could be viewed as an improvement of global natural capital; increasing stability and reducing criticality.

(iii) Depleting a non-renewable resource which has no substitutes and upon which society depends. This type of concern drove the debate over British dependence upon coal at the turn of the century: the coal question (Jevons, 1909). The modern concern is where a non-renewable resource is critical to human systems in an ecological sense and as a result there is no option but to maintain the current stock. Thus, the approach of Nordhaus (1982) to optimally deplete the capacity of the atmosphere to absorb carbon dioxide raises serious alarm amongst ecologists, but is merely the efficient use of scarce resources to some economists.

This last point raises a distinction between substituting for exhausted elements of natural capital in economic processes, and substituting for these same elements of natural capital in ecological processes. Ignorance of ecological thresholds means human society could approach a threshold of system tolerance while the element of critical natural capital being depleted was (in economic terms) still relatively abundant. At such a point there might be little direct economic pressure to seek and develop substitutes, although there would be clear ecological reasons for doing so (Clayton and Radcliffe 1995). Yet the uncertainty over potential outcomes is used by the anti-environmentalist lobby to argue that ecosystems are robust until science proves otherwise (eg., Lehr, 1992). This criticism is worth addressing directly because natural capital starts to become more relevant once both uncertainty and ignorance are considered.

III. UNCERTAINTY AND IGNORANCE

A case against the view that has been behind much environmental concern, variously referred to as "limits to growth", "ecodoom", or "neo-Malthusian", is based on an assessment of the probability that the view is incorrect. The dominant approach to an uncertain world is to try to reduce potential future states to probabilistic events (e.g., economic expected utility models). This requires the estimation of the risk associated with every possible predicted outcome. Practitioners and advocates of this methodology tend to neglect the several, questionable, implicit assumptions it requires:

(i) A cause and effect relationship can be established to determine the outcomes to be included in the set of possible future states. However, this is often impossible when dealing with sustainability because some of the connections between the dimensions of the sustainability problem are poorly understood.

(ii) Probabilities are assumed to be associated with all future states of the world. Although, the action leading to an event may be recognized as a possible state without a probability being attached to the outcome. Thus, an event can be expressed as uncertain yet have no associated probability of occurrence. The probability itself may be unknown or non-existent. (Such a division of risk and uncertainty can be found in Keynes [1921] 1973).

(iii) The type of missing knowledge being analyzed is assumed to be the risk associated with the occurrence of outcomes. However, all the models of the behaviour of complex systems, such as environmental and economic systems or their interactions, are imprecise and limited in their scope. These limitations arise for a number of reasons: ignorance about a particular system, ignorance about the behaviour of a class of systems, and the indeterminate nature of some complex systems (which can become chaotic at various points). This means the behaviour of such systems can only be modelled in probabilistic terms, for limited domains, or for a limited time.

(iv) The distribution of risk over space and time is assumed unimportant when judging appropriate action. Yet, many decisions involve choosing between options that have different risks for different people at different times. For example, a small risk of a major disaster (e.g., a 0.01% chance of a major disaster killing 10,000 people) compared to a large risk of a small disaster (e.g., a 100% chance of killing 1 person) can give the same expected outcome in terms of expected losses (one statistical life). In practice, people are sensibly concerned about the distribution of such risks. These types of decisions involve making judgements as to the priorities of society. The choice of the appropriate course of action, given a full and accurate picture of the risks associated with different outcomes, is a political and moral issue.

Thus, there are some areas of ignorance which cannot be easily placed into the framework of knowledge about systems. For a categorization and explanation of types of ignorance see Faber et al. (1992). In general, where altering the potentialities of systems causes changes which are, in principle, unpredictable the appropriate response is to maintain options. This implies accepting the importance of different views on the same problem and questioning current knowledge. Stirling (1994) argues that a rigorous approach to ignorance is feasible and, learning from operations research, would emphasise criteria of flexibility and reversibility. Walters (1986) has argued for a head on approach to issues of uncertainty, that ignorance needs to be recognised as a first step to knowledge, and that resource management must be adaptive in the face of ignorance.

Now reconsider the role of natural capital and how it fits into the probabilistic framework. Natural capital could be regarded as an insurance premium against known but uncertain future states of the world, where the probability of those states occurring is known or knowable. This would be consistent with an expected utility framework, and could justify a safe minimum standard approach. If the definition of natural capital as critical is adopted, the economy could be "safely" allowed to erode "land" to a hard core of what humans hope they have identified correctly as the essential elements. Further more, technology may substitute natural capital with man-made capital over time as critical functions fall within human capacity to produce. However, even if this utilitarian model and its consequences for how the world is viewed are accepted, caution is required in the manipulation of natural capital.

First, there are elements, substances, and organisms on the planet which have *not yet been utilised directly by humans*. This can be viewed as uncertainty and ignorance over future use patterns. For example, technology might enable the use of a previously untapped or uneconomic resource, or research into causes of disease (eg., cancer) might lead to the recognition of higher-value uses of current resources; adaptation in a dynamic world emphasises the importance of diversity.

Second, many of the features of nature that are directly utilised in economic processes are *dependent on features of nature that are indirectly utilised.* Current biomass depends on an ecological infrastructure which enables flows into human systems but is ignored itself. The sustainable harvest rate of a given species of fish, for example, will depend on the maintenance of the complex web of relationships that constitute the proximate ecology of that species. The sustainability of the harvest rate, then, depends on the way in which that resource is used. Such use patterns can be relatively direct, e.g., the way in which the species itself plus prey, predator and competitor species were caught. However, "use" patterns can also be quite indirect, and so less obvious. For example, emissions of chloroflurocarbons (CFCs) might reduce available fish catches. That is, stratospheric ozone can be depleted by CFCs so allowing higher levels of UV-B radiation to reach the surface of the planet, which would in turn affect the marine biota at the base of the food chain on which the harvested species of fish depends. In this way, uncertainty and ignorance pertain to ecosystems functions in addition to risk.

Once the above arguments are accepted, an optimal level of the insurance premium would be undefinable. Thus, while natural capital can be defined as merely an insurance premium this definition requires the rejection of wider concepts of uncertainty and of ignorance. A constant natural capital stock is now motivated by the need to accept our ignorance, which is in accord with setting ecological constraints upon the economic system.

Admitting there are dimensions and elements of natural capital which generate utility but are unknown or unknowable is still in accord with the use of utilitarianism. The main basis for defining natural capital so far, in this paper, has been neo-classical utilitarian. That is, the consequences of depleting natural capital were judged in terms of its value, and that value was purely based upon anthropocentric utility or satisfaction. This is true from either the economic or ecological perspectives. The ecological approach is fundamentally utilitarian. As described by Foy (1990 p.772), the aim is the definition of physical constraints on the economic system to ensure the sustainability of that system. The constraints based on ecological criteria are concerned with the instrumental value of other species and the environmental systems for human life. However, Foy also notes and alludes to, but fails to discuss, a second set of constraints based upon ethical considerations of duties to future generations and other species.

Our discussion has also excluded consideration of other living beings which are elements of natural capital. This raises questions as to the extent to which human-animals can legitimately regard such elements as resources for their use, which in turn depends upon the moral standing of non-human beings, the extent to which they can feel pain, and the extent to which this is acknowledged. More generally, natural capital as defined so far is an inadequate expression of the components of the world system, and the justifications for its maintenance are being driven by more than economic and ecological considerations.

IV. BEYOND THE UTILITY OF NATURAL CAPITAL

A utilitarian analysis of natural capital is dependent upon the value of that capital in its current state as opposed to in an alternative use. That is, the use of natural capital is determined by its instrumental value. Economics assumes such valuation of alternatives can be carried out via assessing the willingness-to-pay (or willingness-to-accept compensation) of individuals. Thus, at some level the cost of preserving natural capital will exceed the willingness-to-pay for that use and it will be depleted: maximizing utility. Such a process may be perfectly reasonable from a utilitarian perspective, but if society accepts the existence of values in nature which are outside of the human calculus a conflict will arise. For a society aiming to protect such natural values willingness-to-pay is a redundant concept and natural capital will take on a different meaning. The difference can be regarded as the realisation of an intrinsic value in nature as well as in man (i.e., some values are not anthropocentric although they are recognised by humans).

A utilitarian philosophy sees only instrumental value in acts but intrinsic value in the consequences of those acts: consequentialism. Human welfare, or happiness, is then seen as the only intrinsically valuable thing: an anthropocentric value system. Under this anthropocentric view all other things are valuable only in so far as they serve to increase human welfare. The rightness or wrongness of an act is determined by the results that flow from it. Under Bentham's philosophy pain is bad, pleasure good and acts can be judged on the net outcome; a good act is one creating more pleasure than pain.

Preservation of natural capital under the utilitarian value system is judged by the results in terms of human welfare. Thus, the reasons for conserving specific sites (e.g., old growth forest in the Pacific Northwest, or Scottish peat bogs) will include the potential for scientific research, maintenance of genetic diversity for medicine and agriculture, recreation, solace, and aesthetic enjoyment. These instrumental values by their influence on human welfare suggest the potential for the economic analysis of preservation benefits. Maintenance of natural capital is then only one possible alternative use of the site and must be weighed against others which may provide greater human welfare. For example, in the U.K. , as the need for more roads increases the more Sites of Special Scientific Interest (nominally out of bounds to development) will be developed, unless the utility value they posses increases (Spash and Simpson 1993).

This raises many issues concerning environmental valuation, cost-benefit analysis, and obligations to other species or generations, and most fundamentally the potential for trade-offs. Maintenance of natural capital is but one goal in society and can, under a utilitarian philosophy, be over-ridden by other human interests. Where the value of a specific type of natural capital, compared to development use, is deemed relatively low the site will be destroyed by roads, housing estates, or resource extraction. Thus, supporters of the utilitarian philosophy, such as Passmore (1974), cannot, and would not wish to, preclude any area from some eventual development.

This anthropocentric view of the world can be broadened by the inclusion of animals in the utilitarian calculus. Indeed Bentham ([1789] 1970) saw their inclusion as a part of the utilitarian system which he proposed. The "greatest happiness" included avoiding pain and suffering of animals and creating pleasure for them. As long as animals can suffer, avoidance of animal suffering increases utility. Within this structure a hierarchy of sensitivities has been suggested: attributing the highest sensitivity to humans. In terms of natural capital maintenance the implications of including the utility of animals would undoubtably be extensive. However, there is no easy way to estimate the preferences of animals or assess their willingness-to-pay! The idea of including animals starts to move economics into the realm of moral philosophy, and deep ecology.

A step beyond the utilitarian (including non-human-animals) argument is the appeal to rights, deontological ethical theories, and intrinsic value in things as well as humans. This is reflected in Aldo Leopold's land ethic which implies a basic right of natural beings to continue existing in a natural state. As Leopold states ([1949] 1987 pp.224-225):

> "The 'key-log' which must be moved to release the evolutionary process for an ethic is simply this: quit thinking about decent land-use as solely an economic problem. Examine each question in terms of what is ethically and esthetically right, as well as what is economically expedient. A thing is right when it tends to preserve the integrity, stability, and beauty of the biotic community. It is wrong when it tends otherwise."

The concept of 'rights' for flora, fauna, and animals can form an absolute constraint on various forms of action regardless of the benefits. Rights operate to provide those individuals or things that hold them with moral standing. That is, status is an end in itself rather than a means to an end. Deontological ethical theories attribute intrinsic value to features of acts themselves. Respectful treatment of natural entities and natural systems would then rule out certain types of exploitative acts on deontological grounds (Rodman, 1983). The use of natural entities and systems as objects and resources of instrumental value could be precluded on grounds of respect and the obligation of non-interference in anything with internal self-direction and self-regulation.

As mentioned earlier, something which is non-critical for human life could easily be critical for non-humans. There are then two aspects to the argument for natural capital maintenance: the instrumental values recognised by utilitarianism, including ecological human criticality, and in addition intrinsic values and ecological non-human criticality. There are of course many issues underlying the recognition of non-human animal rights the foremost of which is the problem of conflicts of interest. One suggestions in this case is that rights can be relaxed and perhaps made more generally acceptable when based upon interests and allowing for ranking of rights, see Attfield (1981). The point to be made here is that recognizing the general concepts encapsulated by 'rights' is an important motivation for the belief in constant natural capital stock, and non-human intrinsic value is implicit in the stance of economists arguing for constant natural capital.

Holland (1994) has argued that intrinsic values lie behind the position of authors pushing for constant natural capital from the social scientific approach, and in particular Pearce et al.

(1989). The latter authors' argument for constant natural capital is supposedly derived from a sustainability criteria based upon justice for future generations. However, constant natural capital is argued by Holland to be an implausible logical outcome of a theory of sustainability based exclusively on the aim of securing justice for future generations; a point which also follows from Commons and Perrings (1992). The justification for natural capital is apparently non-human intrinsic value. However, Turner and Pearce (1990) claim (in a paper uncited by Holland) that by taking care of justice for future generations of human animals the concerns of future non-human animals will be largely met. There is no need to acknowledged the latter to have intrinsic values which the authors regard as radical and a waste of economists time. As Turner and Pearce (1990 pp.31-32) state:

> "We have argued that an ethic 'for the use of the environment', which restricts rights to humans and recognises primarily only instrumental value in nature, can in any case offer sufficient safeguards. More progress may be made if the analysts turned their attention to the individualist basis of utilitarianism and conventional economics."

More than this, the concept of intrinsic values in non-humans is positively dangerous for three reasons (Turner and Pearce 1990 p.34):

> "(i) it is stultifying of development and therefore has high social costs in terms of development benefits foregone; (ii) it is conducive to social injustice by defying development benefits to the poorest members of the community, now and in the future; (iii) it is redundant in that the modified sustainability approach generates many of the benefits alleged to accrue from the concern for intrinsic values."

This modified sustainability approach actually claims to hold a physical stock of natural capital constant by compensating projects (discussed in more detail in the next section). The constancy of the stock implies it is then outside of economic development criteria, such as cost-benefit analysis, but inexplicably avoids criticisms (i) and (ii) above. This paper also faces the problem of finding a justification for a constant physical capital rule purely on grounds of economic efficiency and intergenerational equity (i.e., Holland's arguments still apply). None of the points is explained so the reader is left wondering: what are these benefits in point (iii), how are these benefits met, and why bother with them if the authors can allege their nonexistence?

In fact, this rejection of non-human intrinsic values is strangely qualified by the apparent need to make the concept fit into the economic utilitarian model. Turner and Pearce (1990 p.16) speculate that existence values may encompass non-utilitarian values and later (p.29) believe that existence values are the means whereby individuals reveal their concern for non-human intrinsic values. Pearce, Markandya and Barbier (1989 p.62) boldly claim "INTRINSIC VALUE = EXISTENCE VALUE" and thereafter only discuss the latter, which they explain can be measured by the contingent valuation method. Although, they note (p.77) that existence values may reflect some judgement about the rights of non-human beings. Thus, the non-human intrinsic value concept has become serious enough for neoclassical economists to try and adopt: creating this rather confused literature.

Ofcourse a non-utilitarian belief cannot, by definition, be squeezed into a utilitarian model. Individuals willing-to-pay for species preservation or biodiversity may be showing respect for the non-human intrinsic value they recognise but this trade price fails to measure the intrinsic value. In the same way paying to help save a person's life fails to reflect the value of their life. The reflection of intrinsic values as rights would result in what neoclassical economists term lexicographic preferences or non-compensatory choices. In this case intrinsic values in non-human animals, plants or ecosystems are recognised by individuals as a serious constraint on economic trade-offs. Recent studies show approximately 25% of respondents to contingent valuation surveys of biodiversity and wildlife show rights based beliefs by ***refusing to bid anything*** (Spash and Hanley 1995, Stevens et al. 1991).

V. HOW TO MAINTAIN NATURAL CAPITAL?

We have identified two core reasons for wanting to designate a class of inputs to production as natural capital: (i) criticality, (ii) intrinsic value. The main approaches to natural capital maintenance can be evaluated in the light of the preceding discussion. Various suggestions have been advanced to deal with the issues arising from resource flow and pollution absorption capacity limitations. These strategies are set out below, moving from standard economic tools through the development of constraints to a systems approach. The emphasis is on the proposed method of assessing natural capital loss and so identifying the stock to be maintained rather than on the instruments for actual maintenance (i.e., legal, social, economic enforcement measures).

(i) Maintaining Total Economic Value

Some economists have suggested that the value of the environment is summed up in the concept of a "total economic value" (Freeman 1993 p.147, Pearce et al. 1990, Pearce and Turner 1990, Mitchell and Carson 1989 p.59). This approach applies a standard economic analysis of free market systems failure; suggesting the price system is defective in terms of reflecting relative scarcity. In order to assess how far the natural capital stock has been over (or under) used, the value of natural capital is assessed using environmental cost-benefit analysis. A market failure is then corrected by increasing or decreasing what is regarded as either the under or over use of natural capital. Typically environmental goods and services would be undervalued and resource use would as a result be excessive. This approach is normally advised for use at the project level where small changes in development are threatening elements of natural capital. The method essentially aims to assess the value of the income flows lost.

Problems arise due to the limited ability of human preferences expressed in a market place to encompass all the information and values identified in the roles of natural capital. First, the existence of perfect information in economic models avoids the issue of how introducing information affects preferences as opposed to merely informing decisions. Second, there is no evidence that human preferences expressed through the market place relate to the relative criticality (as opposed to relative economic scarcity) of forms of natural capital. People appear to value their environmental status quo rather than a healthy ecology, and have objected to the removal of slag heaps and the reafforestation of denuded hill-sides. Similarly, a higher priority is often given to environmental change that happens quickly rather than slowly, probably because rapid change is more psychologically salient (although long-term environmental change may be more serious). Furthermore, individuals tend to place higher economic values on organisms at the tops of food chains, although species at the bottom of food chains are usually much more ecologically significant (donating to save pandas, rather than bamboo). Thus, anthropomorphic values as reflected in the market place diverge from ecological values.

More generally, reliance on this idea of assessing the value of the damage associated with natural capital depletion requires that the features of capital lost are commodities, the consumerist approach (see Spash 1995). If nature fails to fit in to this framework it is excluded from being valued even if of some utility. Maintenance of value can be consistent with depleting a resource, or driving a species to near extinction (i.e., a reduced quantity and increased price). For example, speculators are currently hoarding White Rhino horns and driving the resource to extinction in order to raise the value of their holdings. The valuations are also entirely anthropocentric and so deny the existence of intrinsic values in nature. Thus, natural capital would be physically depletable.

(ii) Compensating Projects

This approach, proposed by Klaasen and Botterweg (1976), relies on an adaptation of the free market system approach by establishing shadow projects that would compensate for the physical loss of natural capital in physical terms. This technique concentrates on natural capital loss at the level of projects or groups of projects. A developer whether a government agency or private individual would provide a project that enhanced environmental functions as compensation for those lost as a result of the development project. Daly (1990) has argued for "quasi-sustainable" use of nonrenewables by requiring that any investment in the exploitation of a renewable resource must be matched by a compensating investment in a renewable substitute.

Pearce and associates, who are proponents of total economic value, also support a variant of the compensating projects idea: in this case, by restoration and rehabilitation of the environment. However, they believe this would be too restrictive on a project by project basis; "we cannot require each tree, each piece of lost soil, each fine view to be restored" (Pearce and Turner 1990 p.225), and therefore suggest a "portfolio" approach where the sum of damages due to development projects is balanced by "deliberate creation and augmentation of environmental capital". They would not measure the success of compensation through a cost-benefit analysis, and thus accept an exogenous constraint upon the economic system. However, as discussed in the previous section, the (apparently non-utilitarian) justification for external constraints is left unclear by these authors.

More generally, the aim in adopting a shadow project approach would seem to be to avoid the monetary valuation issues. This could in theory include a recognition of the rights of say animals, species or ecosystems. For example, species rights might be reflected in the destruction of one habitat requiring the construction of another elsewhere. Yet, similar problems to the monetary valuation approach remain. Exactly what is adequate compensation and how is it to be measured? The portfolio approach assumes that various ecosystem features can be aggregated together, and then humans can "create" natural capital to match at some other group of sites. A project level approach is therefore preferable in order to avoid such issues. However, this still begs the question as to what compensation mankind can make for ecosystem destruction unless the ecosystem is identically reproduced somewhere else on "unused" land. The shadow projects themselves will change the stock of natural capital. For example, if a meadow were to be flooded to create a replacement for a wetland area destroyed by development the stock of natural capital is reduced by one meadow (after the compensating project). As Munro and Hanley (1991) note, only if the land on which the shadow project is to be "created" is ecologically worthless can the stock of natural capital be held constant by a compensating project. These same authors also point out that planning agencies with multiple goals might trade-off various project features so that natural capital would be reduced by shadow projects.

(iii) Scientific Thresholds

A third approach would be to allow a "scientific" determination of the limits to be set on the use of natural capital. This views the world as a complex machine which needs close analysis by atomistic reductionism to identify all the working parts and how they fit together. The maintenance of natural capital would then be achieved by defining a critical natural capital stock, which at the limit would include all natural capital, to be preserved absolutely. Victor (1991) has argued in favour of a set of biophysical constraints on an economy which would define the conditions of sustainability in direct bio-physical units. Thus, the requirements of the ecosystem are to be taken into account in so far as they support the sustainability of the economic system. Common and Perrings (1992 pp.30-31) define an ecological-economic approach with resources allocated so as to be consistent with the protection of stability in both the system as a whole and key components of the system. Their ecological sustainability is a physical concept based upon population indicators (for stability) and indicators of responsiveness of systems parameters to perturbations in resource stocks (for resilience).

The levels to which scientific reductionism can assess ecosystem constraints is limited by the current level of human knowledge and ultimately irreducible ignorance (Faber et al. 1992). Thus, gaining a consensus on the appropriate thresholds is far from discovering an "objective" truth. As science tends to learn by doing there is also some risk of awaiting the evidence, and getting confirmation of critical natural capital loss once it has become irreversible, or the system has started an irrevocable transition. However, in general some aspect of this approach will be necessary in the maintenance of natural capital.

The scientific threshold approach could be used to acknowledge non-human intrinsic values and respect them. Scientific research into system boundaries could include the impacts on non-anthropocentric values and set limits which allowed for a wide range of necessary conditions. This would require a recognition by society of the values which scientist are to serve. Currently the drive towards market economies negates concerns for either intrinsic values or ecological stability even when the regulatory authority may recognise their importance (Spash and Simpson 1993).

In theory, this scientific approach is operated by the United States in their use of primary air pollution standards which aim to protect human health regardless of cost. However, the standards have had enforcement problems with some regions consistently failing to meet the requirements. This is worrying when the scientific evidence is in favour of tightening standards even further. For example, tropospheric ozone (e.g., Los Angeles smogs) was restricted to protect human health, but the old, asthmatic and very young are still susceptible to harm. In addition, the initial lack of data when designating a threshold means long-term effects tend to be ignored. Long-term exposure to relatively low doses of ozone can shorten life and affect lung development. These problems require a tightening of the standard, but as the standard is already exceeded the problem of how to achieve the new goal arises. Some economists would then argue that the objective scientific approach be replaced by cost-benefit analysis as the appropriate decision-making tool to decide the acceptable probability of failure to meet a given standard, the margin of safety (Krupnick 1988 pp.9-12, Freeman 1993 p.266). Others might regard the issue more widely and desire a change in human behaviour, in this case new approaches to transportation. The point is that scientific information can easily require life style affirmation or change but the decision over the life style adopted is outside of the scientists remit. Thus, Common and Perrings (1992) argue for overriding consumer sovereignty where it supports ecologically unsustainable preferences and technologies, but they fail to address the issue of who does the overriding or how.

The enforcement of scientific thresholds raises many issues on the role of scientific judgement in the decision-making process (issues which are also relevant to the policy prescriptions of positive economics). Scientific evidence on environmental problems is normally a prerequisite for action. However, this is very different from allowing politically appointed oligarchies of "experts" decide upon the appropriate levels of natural capital. The dangers of oligarchies in action can be seen by another example from the US; appeals against the Endangered Species Act lead to the creation of a politically appointed quango of non-experts with the remit to decide whether a development project is actually a threat to a species. The seven person Endangered Species Committee has been nicknamed the "God Squad", due to their power of life and death in cases such as the Mount Graham red squirrel and the northern spotted owl (National Wildlife Federation 1991). Replacing the committee with expert scientists leaves the political and economic issues unresolved. For example, part of the issue here concerns the perception of risk to a particular species. The general public has been observed to reject very low-probability, high-loss risks which experts judge to be acceptable (Freeman 1993 p.260). Thus, the experts could vastly underestimate the potential welfare costs that these risks impose upon people.

The argument here is about whose probabilities of uncertain future events count, the experts or the publics, and whose preferences count, the select committee or those who face the risk/loss. This suggests that the scientific priorities should be set by the wider community, rather than just the scientific community. For example, biodiversity protection has been approached from two directions, one aimed at species preservation (as in the US) and the other at ecosystems conservation (as in the UK). Hence the problem of the God Squad has been avoided in the UK (although there are other problems, see Spash and Simpson 1993). Science is itself at least in part a social activity, and its priorities are influenced by political and economic factors. Outside of the realm of the "enlightened philosopher king", science cannot provide constraints on behaviour based on pure, abstract and absolute truth. Furthermore, even given a scientific consensus as to the optimal target for some particular use of natural capital, there will be a number of political and economic choices to be made as to how to achieve that target. Thus, intrinsic non-human values and duties to future generations take on a similar role in constraining scientists that ecology has been argued to take in constraining economics. These issues are of high priority given the role of science in environmental policy formation.

(iv) Systems Approach

At the opposite extreme to atomistic reductionism is the attempt to consider the whole system in an holistic manner. Walters (1986) describes how resource management can benefit from systems modelling even when the models themselves are never actually employed. The process of conceptualising systems boundaries in an interdisciplinary setting is useful in and of itself. He also emphasises the need to address uncertainty and the role of adaptive management rather than optimal solutions. Extended systems approaches have been suggested by Burkes and Folke (1992) and developed by Clayton and Radcliffe (1995).

The vital task, in the development of strategies for the sustainable management of natural capital, is to integrate the critical scientific, socio-economic and philosophical information perspectives. Scientific research allows the development of understanding of the behaviour of the biological, ecological, geochemical and other processes that shape the global environment: allowing society to monitor change, identify trends and predict possible outcomes. However, all such knowledge is probabilistic, and all decisions must be made in light of risk, uncertainty and ignorance. Thus, there will always be political and economic choices to be made in meeting any given scientifically determined target. Socio-economic analysis is essential if we are to develop techniques for assigning and incorporating environmental values, where appropriate, in to economic and related decision-making. This allows the choice of economic tools to achieve desired ends with the minimum of means and adverse effects. Other non-efficiency goals are also of concern here, e.g., redistributive consequences. Philosophical analysis reveals the mix of assumptions that underlie human decision-making processes. In this way long-term and diffuse relationships between actions and consequences can be brought into a practical ethical framework for decision-making.

In practice, therefore, environmental questions are inextricably interlinked with social, economic and cultural values. Economic systems determine the rate and route of flows of energy and resources from the environment into patterns of human use, and the rate and route of flows of waste and energy and materials from human economic operations back into the environment. These economic systems are, in turn, imbued by cultural values, and underpinned by social and psychological models that influence the way in which people understand their options and make choices. The need is to have some way of incorporating information from such different domains into a single decision-making process.

One approach is to try to map all the relevant information on to one domain. This underlies the attempt in environmental economics, for example, to assign values to ecological and social phenomena, so that they can be brought into cost-benefit analysis. There are three critical problems with this approach. First, information may be lost as knowledge from other domains is translated and mapped. Second, the dynamic interaction of complex ecological and economic systems is neglected and cannot be understood. Third, the way in which information is used, the relationship between information and power, makes the methodology chosen for the assignation of values and weightings highly significant, but this is usually invisible by the time the data has been processed.

Systems theory can offer a multi-dimensional framework in which information from different domains can be integrated without being forced into one-dimensional mapping. This integration of diverse information can be achieved in various ways. One way is to model the systems concerned in an attempt to draw all key dimensions present into a single model. This is, in general, a highly mathematical approach, and is usually applied to relatively 'hard' and quantifiable systems. A more generalist systems approach, which can be extended to 'soft' systems that cannot be quantified on an equivalent basis, emphasises the development of an understanding of the pattern of interaction between the systems concerned. This usually involves drawing on a range of models and analytical tools and constructs developed in the various specialist disciplines involved.

The mathematical and the generalist approaches both require the development of a decision-making process that can accommodate change in a number of non-equivalent dimensions simultaneously. One way in which this can be done is using multiple indices. Various kinds of graphics can then be used to show movement on these multiple indices, to demonstrate change over time, or on a compare-and-contrast basis, to demonstrate the difference between two or more development options in terms of a complete profile of costs and benefits.

Clayton and Radcliffe (1995) employ 'Sustainability Assessment Maps' (SAMs) to demonstrate this method (a related but simpler approach was employed by Brendan 1992). A SAM consists of a diagram in which each of the critical dimensions in a complex problem is represented by an axis. Measurement of change or indications of priorities are then mapped onto these axes. The purpose of this approach is to emphasise rather than conceal conflicting values, and to do so in a way that is accessible and intuitive.

When making a development decision the first step is to identify the critical areas of change (axes of concern) which are key factors in the development process. These could include monetary costs and benefits, profits, number of jobs, types of physical environmental impact, quantity and quality changes in natural capital stock and so on. The main development options are assessed on the same basis and scored on all of the axes of concern. The scores are then displayed in a SAM graphic. Each option can, as a result, be compared in terms of its overall profile, and in terms of the balance of advantages and disadvantages relative to alternative options. The profiles developed using SAMs for a particular development option can be subtracted from an alternative option to give a new combined SAM which shows the net difference.

In order to help explain how SAMs would operate we will briefly outline an example using energy policy. The example is for illustrative purposes and may therefore be unrepresentative of actual profiles. Consider a power company deciding whether to install new capacity and facing three alternatives: coal burning, nuclear power or a tidal barrage. Each option can be considered in turn.

The coal burning power station will produce large volumes of chemical waste such as carbon dioxide, sulphur oxides and alkaline ash. The carbon dioxide and sulphur emissions will enter the atmosphere with long term impacts. The ash might be disposed of in lagoons covering sizable areas near the station. The local and short term impacts are judged to be within local ecological limits as the chosen site is industrialised; although, the lagoons may irreversible damage local biota. On balance the risk associated with this option is relatively low. However, the non-local and long-term picture is less favourable with contributions to the enhanced greenhouse effect and acidic deposition. This option also incurs up stream environmental costs e.g., mining and transporting coal.

Nuclear power presents a complex range of emissions including radioactive isotopes. The bulk of high-level waste disposal is to be in temporary underground storage. Local and short-term impacts are minimal, which is important because the site is remote and on an environmentally sensitive part of the coast. Long-term storage of high-level waste poses the risk of disaster with a low probability, and passes the problem along to future generations. Upstream costs include uranium mining, fuel processing, and transport of radioactive fuel and waste products.

The tidal barrage has waste products largely limited to the construction phase, unlike the other two options. However, the barrage will flood and destroy the mudflats of the estuary where it is to be built. The estuary is an internationally important site for migratory birds and has a unique endangered plant species. This gives a profile of high site sensitivity and local ecological damage. Yet the long-term and regional/global profile is very favourable with damage limited to a single site.

In addition to these environmental considerations the construction and operating costs are included. The power company might then proceed with an application to a government agency or during the planning process another option may be identified. Thus, the option of investing in energy conservation could be added to the social decision of how best to use the available resources. These different options are to be analyzed upon several different axes and twenty one have been selected for the current analysis; these axes are: critical natural change, other natural change, site value, aesthetic impact, impact scale and risk, emissions (air, land, water, auditory and electromagnetic and ionising radiation), net capital growth, application of capital commitment, employment impact, total material and energy input, and resource depletion (fossil fuel, mineral, soils, water and biotic).

Some examples of the resulting SAMs are shown in Figures 1, 2 and 3. There are three concentric rings which signify, moving from the centre outward, regional, national and global impacts. Each option can be shown individually as is done in Figure 1 for nuclear power and in Figure 2 for energy conservation. Next two options can be compared (combined) on the same SAM as is done in Figure 3 for nuclear power versus energy conservation.

The value of the exercise lies in using axes that allow reliable comparisons to be made between options, and to make these choices explicit, so that it is always possible to identify and check assumptions and calculations. SAMs can also be used to clarify areas of disagreement: using the combining process to differentiate scores in two SAMs to create a third, as in Figure 3. Groups expressing different environmental attitudes can consider a development option and express preferred positions on each axis (e.g., location, scale, water pollution). The sets of final patterns from the combined SAM will clearly identify areas and degrees of disagreement. This would allow the recognition of a particular position on a particular axis as being 'inviolable'. Other axes may be seen as negotiable within limits or of little concern in terms of conflict resolution.

The use of concentric overlays in plotting SAMs can show a range of aspects due to a development project on a single diagram. For example, geographic distribution of impacts could be shown within concentric overlays representing local, regional and global effects, as in the figures presented here. Similarly, intragenerational versus intergenerational impacts can be shown by differentiating each ring by discrete time periods.

In the final instance, where a yes/no decision has to be made, the information must be collapsed into a single dimension. At that stage SAMs have no advantage over environmental cost-benefit analysis. However, the advantage of SAMs over cost-benefit analysis lies in their function as decision-making aids. The purpose of SAMs is to: make trade-offs more explicit, incorporate incommensurable values, increase accessability to the decision-making process, encourage identification of a the full range of options, and enable effective monitoring of the wider effects of decisions over time.

VI. CONCLUSIONS

The justification for wanting to define a set of inputs to production as natural capital seems to require the recognition of values which fall outside of the neoclassical economic model, and therefore provide constraints upon that model. One set of values derives from human ignorance of ecosystems and the need to protect their stability and resilience. The general public is unable to place a willingness-to-pay value on aspects of ecosystems and their functions which even experts find difficult to explain to each other. The drive towards utility maximisation in these circumstances is due to the desires of public agencies rather than a reflection of how individuals actually operate. Individuals confronted by complex problems are likely to refuse to make trade-offs which reduce their ability to adapt to future circumstances, rather than make an irreversible decision based on maximising current economic gains while facing information limited to their current context. This is a testable hypotheses for which some evidence has been cited.

The second set of values appeals to human acceptance of a wider range of moral agents than themselves. The recognition of non-human intrinsic values provides reasons for preventing economic exploitation of natural capital. Under the utilitarian philosophy there can never be absolute or permanent protection. If the arguments of those favouring the existence of intrinsic values in nature are adopted, such protection is justified, and natural capital would be excluded from economic calculations. The problem of maintaining natural capital is then altered into identifying and protecting natural objects and species on grounds of what Hargrove (1989) calls intrinsic beauty and interest.

These external constraints leave economic systems facing limits which still need to be defined and accepted by human society. In looking at the approaches to forming and maintaining these constraints in terms of natural capital maintenance we have argued against narrow views of natural capital in terms of either monetary value or physical characteristics. While such definitions reign the trade-offs they allow require many questionable assumptions about human abilities to recreate, understand and manipulate natural systems. The gaps in human knowledge, and our apparent inability to ever fill those gaps makes the maintenance of the fundamental ecosystems and their diversity a necessary step to achieving the relative stability that is implied by sustainability. Thus, we argue in favour of a pluralistic approach which can incorporate a variety of information.

This seemingly leaves the formation of constraints in the hands of experts. Yet the dangers of this approach have also been outlined. This drives us towards an appeal for serious consideration of new institutional structures. As a result, perhaps this paper is too much in the vein of current nihilistic thinking on environmental valuation, and the extended systems approach, as offered by SAMs, currently lacks the rigour of the alternatives. (Although, pure systems modelling is itself generally a highly mathematical and rigorous discipline.) However, we are trying to move into a more inclusive debate where different disciplines communicate and the benefits of alternative viewpoints are recognised. Neither the free-market economic system nor the expert scientific oligarchies can be relied upon to decide the basis for natural capital maintenance. In a world economic system totally oriented towards making trade-offs, any attempt to suggest limits to trading must either appeal to an alternative view and definition of natural capital (such as non-anthropocentric values), or recognise the need to fundamentally change the way in which humanity perceives development. Both realisations suggest the need for the consideration of multiple values and perspectives which we suggest an extended systems approach could provide. Underlying this approach is a concern for a more inclusive and holistic view of natural capital maintenance, without which the concept itself becomes meaningless.

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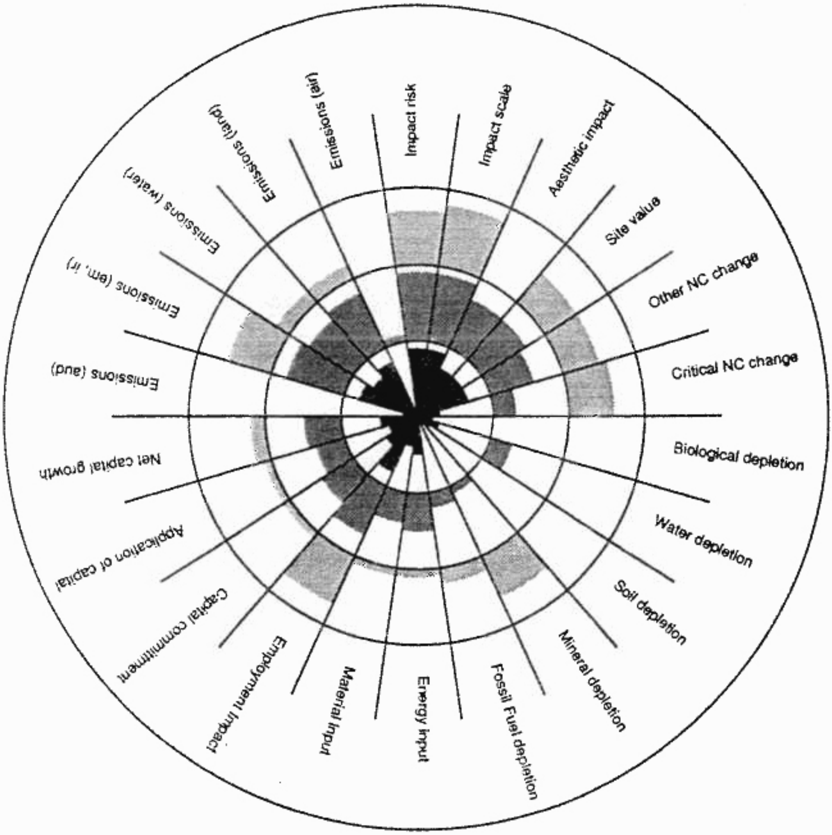
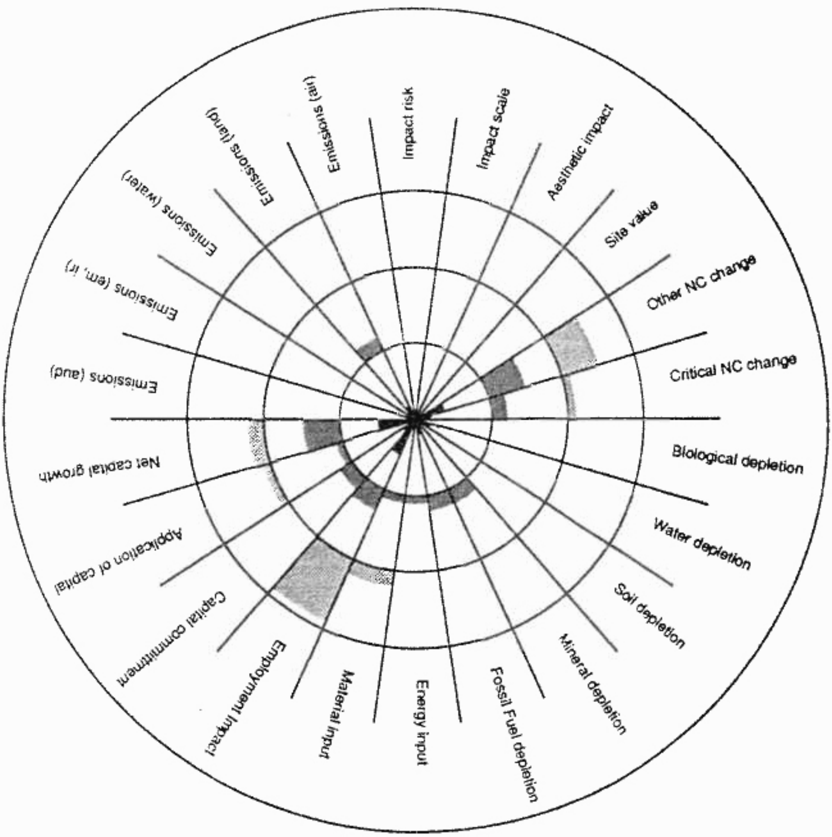
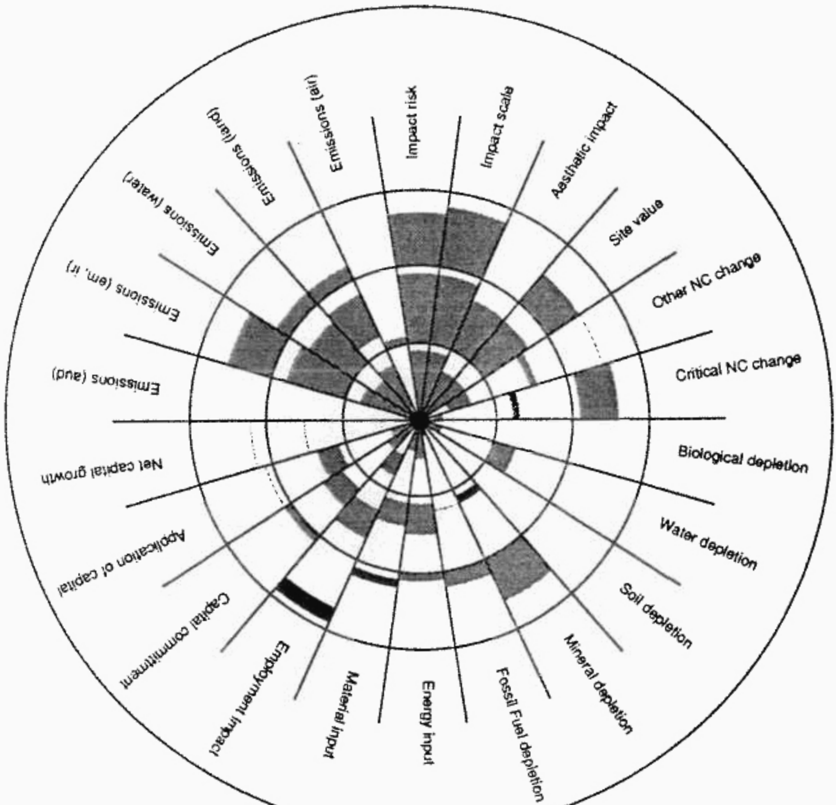


SAM for a new nuclear power station.



SAM for a major energy conservation scheme.



SAM showing the comparison between building a nuclear power station and a major energy conservation programme. Grey bars show indicators upon which the energy conservation scheme has a more favourable rating, and black bars show the converse.

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